

TITLE: SPECIFICATION BASED DETECTION AND REPAIR OF
ERRORS IN DATA STRUCTURES

Inventors: Brian C. Demsky, et al.

Filed: November 26, 2003

MIS-00401

Agent: Anne E. Saturnelli

Reg. No.: 41,290

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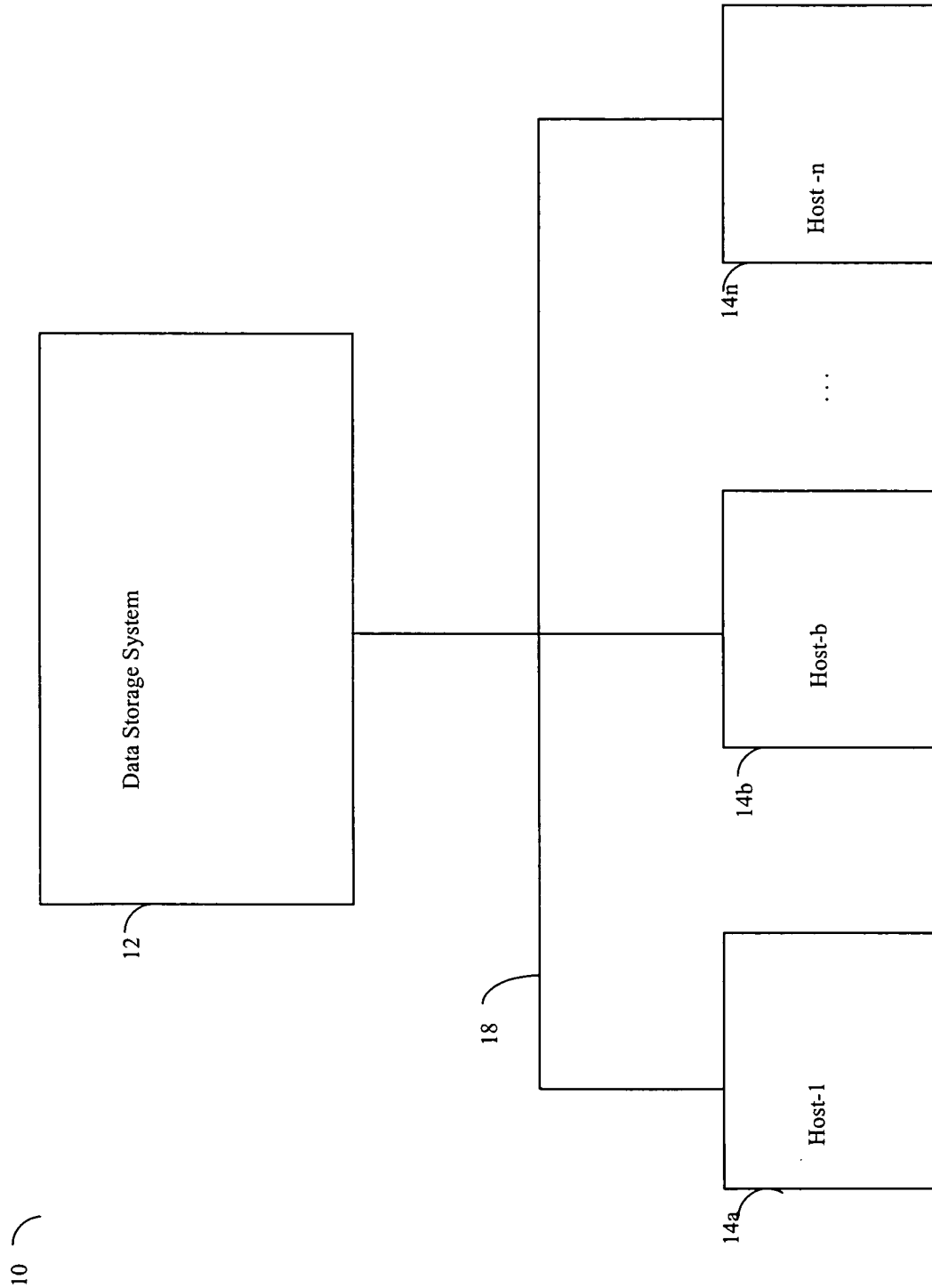


FIGURE 1

**TITLE: SPECIFICATION BASED DETECTION AND REPAIR OF
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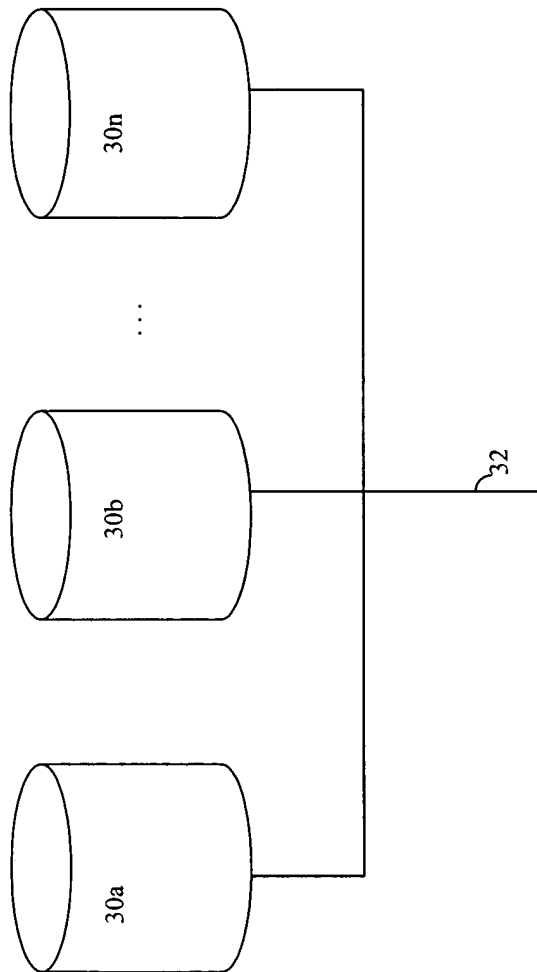


FIGURE 2

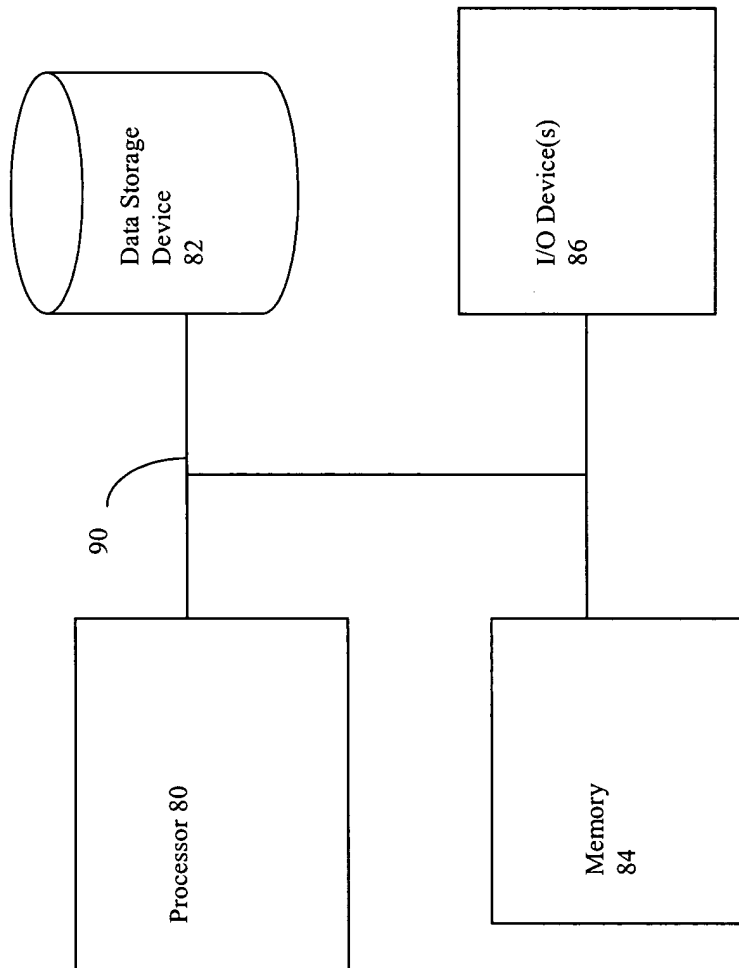


FIGURE 3

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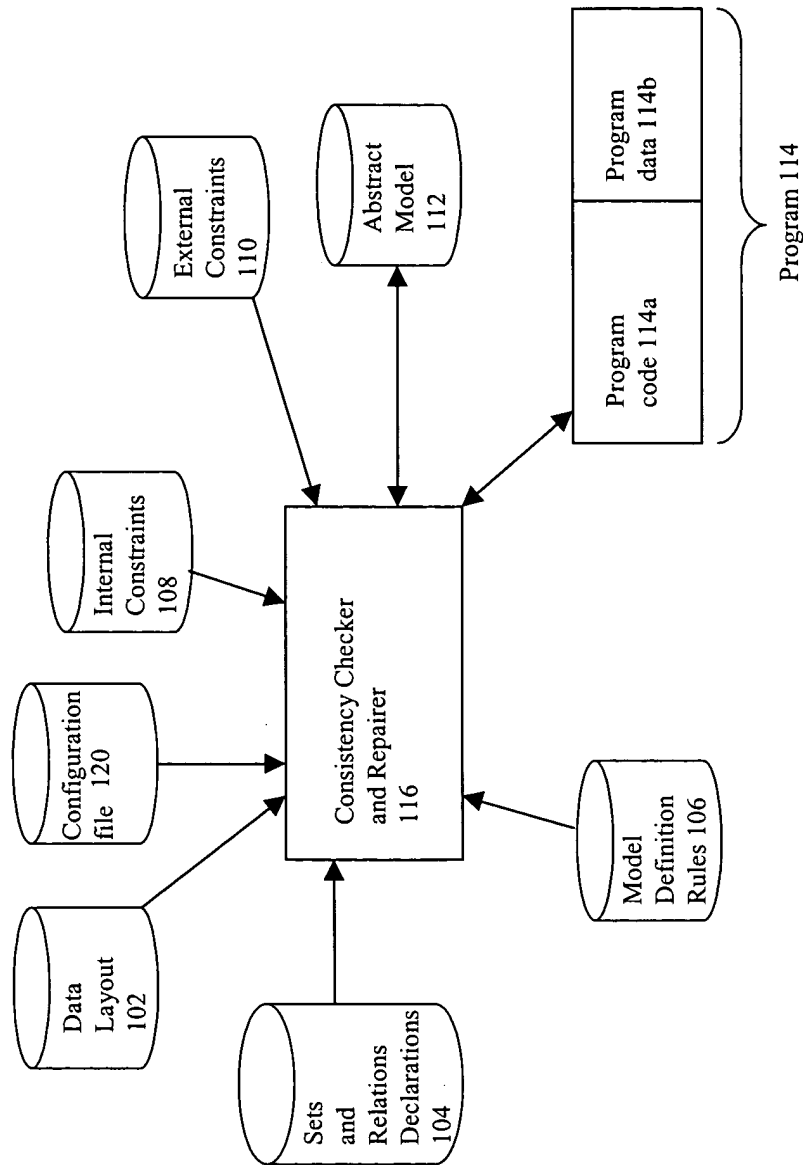


FIGURE 4

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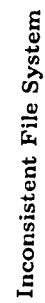


FIGURE 5

structdefn := *struct structname*
 (*subtypes structname*) {*fielddefn**}
fielddefn := *type field*; | *reserved type*; |
 type field[E]; |
 reserved type[E];
type := *boolean* | *byte* | *short* | *int* | *structname* |
 structname *
E := *V* | *number* | *string* | *E.field* |
 E.field[E] | *E - E* | *E + E* | *E/E* | *E * E*

FIGURE 6 Structure Definition Language

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```
struct Entry {  
    byte name[Length];  
    byte valid;  
    int size;  
    int first;  
}  
struct Block { data byte[BlockSize]; }  
struct Disk {  
    Entry table[NumEntries];  
    int FAT[NumBlocks];  
    Block block[NumBlocks];  
}
```

FIGURE 7 . Structure Declarations

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125 { set S of T : Partition S_1, \dots, S_n
relation $R : S_1 \rightarrow S_n$ }

FIGURE 8A

126 { set blocks of integer : partition used | free
relation next : used \rightarrow used; }

FIGURE 8B

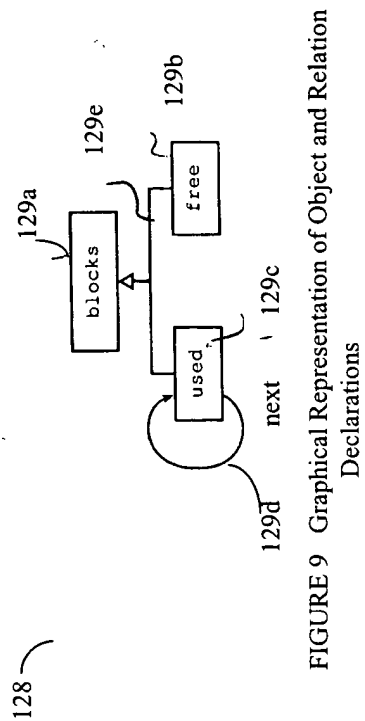
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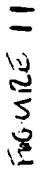
$$\begin{aligned}
 C &:= Q, C \mid G \Rightarrow I \\
 Q &:= \text{for } V \text{ in } S \mid \text{for } \langle V, V \rangle \text{ in } R \mid \\
 &\quad \text{for } V = E \dots E \\
 G &:= G \text{ and } G \mid G \text{ or } G \mid G \mid E = E \mid E < E \mid \text{true} \mid \\
 &\quad (G) \mid E \text{ in } S \mid \langle E, E \rangle \text{ in } R \\
 I &:= E \text{ in } S \mid \langle E, E \rangle \text{ in } R \\
 E &:= V \mid \text{number} \mid \text{string} \mid E.\text{field} \mid \\
 &\quad E.\text{field}[E] \mid E - E \mid E + E \mid E/E \mid E * E
 \end{aligned}$$

FIGURE 10

Model Definition Language

$h_w \in \text{HeapValue} = \text{Bit} \cup \text{Byte} \cup \text{Short} \cup \text{Integer} \cup \text{Struct}$
 $h \in \text{Heap} = \mathcal{P}(\text{Object} \times \text{Field} \times \text{HeapValue} \cup \text{Object} \times \text{Field} \times \mathbb{N} \times \text{HeapValue})$
 $v \in \text{Value} = \mathbb{Z} \cup \text{Boolean} \cup \text{string} \cup \text{Struct}$
 $l \in \text{Local} = \text{Var} \rightarrow \text{Value}$
 $s \in \text{Store} = \text{Value} \times \text{Value} \cup \text{Value}$
 $m \in \text{Model} = \mathcal{P}(\text{Var} \times \text{Store})$
 $\mathcal{R} : C \rightarrow \text{Heap} \rightarrow \text{Local} \rightarrow \text{Model} \rightarrow \text{Model}$
 $\mathcal{E} : E \rightarrow \text{Heap} \rightarrow \text{Local} \rightarrow \text{Model} \rightarrow \text{Value}$
 $\mathcal{G} : G \rightarrow \text{Heap} \rightarrow \text{Local} \rightarrow \text{Model} \rightarrow \text{Boolean}$
 $\mathcal{I} : I \rightarrow \text{Heap} \rightarrow \text{Local} \rightarrow \text{Model} \rightarrow \text{Model}$

$\mathcal{R}[\text{for } V \text{ in } S, C] \ h \ l \ m = \bigcup_{v \in m(S)} \mathcal{R}[C] \ h \ l[V \mapsto v] \ m$
 $\mathcal{R}[\text{for } \langle V_1, V_2 \rangle \text{ in } R, C] \ h \ l \ m = \bigcup_{(v_1, v_2) \in m(R)} \mathcal{R}[C] \ h \ l[V_1 \mapsto v_1][V_2 \mapsto v_2] \ m$
 $\mathcal{R}[\text{for } V = E_1 \dots E_2, C] \ h \ l \ m = \bigcup_{i=1}^{|E|} \mathcal{R}[E_i] \ h \ l \ m \quad \mathcal{R}[C] \ h \ l[V \mapsto i] \ m$
 $\mathcal{R}[G \Rightarrow I] \ h \ l \ m = \text{if } (\mathcal{G}[G] \ h \ l \ m) \text{ then } (\mathcal{I}[I] \ h \ l \ m) \text{ else } m$
 $\mathcal{G}[G_1 \text{ and } G_2] \ h \ l \ m = (\mathcal{G}[G_1] \ h \ l \ m) \wedge (\mathcal{G}[G_2] \ h \ l \ m)$
 $\mathcal{G}[G_1 \text{ or } G_2] \ h \ l \ m = (\mathcal{G}[G_1] \ h \ l \ m) \vee (\mathcal{G}[G_2] \ h \ l \ m)$
 $\mathcal{G}[G] \ h \ l \ m = \neg(\mathcal{G}[G] \ h \ l \ m)$
 $\mathcal{G}[E_1 = E_2] \ h \ l \ m = (\mathcal{E}[E_1] \ h \ l \ m) == (\mathcal{E}[E_2] \ h \ l \ m)$
 $\mathcal{G}[E_1 < E_2] \ h \ l \ m = (\mathcal{E}[E_1] \ h \ l \ m) < (\mathcal{E}[E_2] \ h \ l \ m)$
 $\mathcal{G}[\text{true}] \ h \ l \ m = \text{true}$
 $\mathcal{G}[E \text{ in } S] \ h \ l \ m = \langle S, \mathcal{E}[E] \ h \ l \ m \rangle \in m$
 $\mathcal{G}[\langle E_1, E_2 \rangle \text{ in } R] \ h \ l \ m = \langle R, \langle \mathcal{E}[E_1] \ h \ l \ m, \mathcal{E}[E_2] \ h \ l \ m \rangle \rangle \in m$
 $\mathcal{I}[E \text{ in } S] \ h \ l \ m = m \cup \langle S, \mathcal{E}[E] \ h \ l \ m \rangle$
 $\mathcal{I}[\langle E_1, E_2 \rangle \text{ in } R] \ h \ l \ m = m \cup \langle R, \langle \mathcal{E}[E_1] \ h \ l \ m, \mathcal{E}[E_2] \ h \ l \ m \rangle \rangle$
 $\mathcal{E}[V] \ h \ l \ m = l(V)$
 $\mathcal{E}[\text{number}] \ h \ l \ m = \text{number}$
 $\mathcal{E}[E.\text{field}] \ h \ l \ m = b \text{ such that } \langle (\mathcal{E}[E] \ h \ l \ m), \text{field}, b \rangle \in h$
 $\mathcal{E}[E_1.\text{field}[E_2]] \ h \ l \ m =$
 $\quad c \text{ such that } \langle (\mathcal{E}[E_1] \ h \ l \ m), \text{field}, (\mathcal{E}[E_2] \ h \ l \ m), c \rangle \in h$
 $\mathcal{E}[E_1 \oplus E_2] \ h \ l \ m = \text{primop}(\oplus, (\mathcal{E}[E_1] \ h \ l \ m), (\mathcal{E}[E_2] \ h \ l \ m))$
 $\mathcal{E}[\text{string}] \ h \ l \ m = \text{string}$


Denotational Semantics for Model Definition Language

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```
Disk disk;  
  for i in 0..NumEntries, disk.table[i].valid &&  
    disk.table[i].first < NumBlocks =>  
      disk.table[i].first in used;  
    for b in used, 0 <= disk.FAT[b] &&  
      disk.FAT[b] < NumBlocks => disk.FAT[b] in used;  
    for b in used, 0 <= disk.FAT[b] &&  
      disk.FAT[b] < NumBlocks =>  
        <b,disk.FAT[b]> in next;  
    for b in 0..NumBlocks, !(b in used) => b in free;
```

FIGURE 12A Model Definition Declarations and Rules

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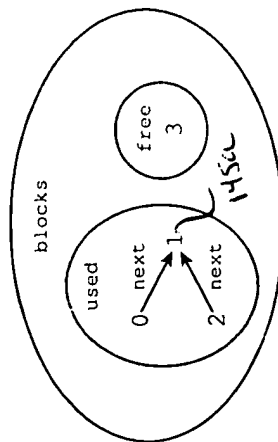


FIG. 16 Inconsistent Model
145a
145b

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$$\begin{aligned}
 C &:= Q, C \mid B \\
 Q &:= \text{for } V \text{ in } S \mid \text{for } V = E \dots E \\
 B &:= B \text{ and } B \mid B \text{ or } B \mid B \mid (B) \mid \\
 &\quad VE = E \mid VE < E \mid VE \leq E \mid VE > E \mid \\
 &\quad VE \geq E \mid V \text{ in } SE \mid \text{size}(SE) = C \mid \\
 &\quad \text{size}(SE) > C \mid \text{size}(SE) \leq C \\
 VE &:= V.R \\
 E &:= V \mid \text{number} \mid \text{string} \mid E + E \mid E - E \mid E/E \mid \\
 &\quad E * E \mid E.R \mid \text{size}(SE) \mid (E) \\
 SE &:= S \mid V.R \mid R.V
 \end{aligned}$$

Internal Constraint Language

FIGURE 13

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$$\begin{aligned}
 v &\in \text{Value} = \text{Number} \cup \text{Boolean} \cup \text{string} \cup \text{Object} \\
 l &\in \text{Local} = \mathcal{P}(\text{Var} \times \text{Value}) \\
 m &\in \text{Model} = \mathcal{P}(\text{Var} \times \text{Store}) \\
 s &\in \text{Store} = \text{Value} \times \text{Value} \cup \text{Value} \\
 \mathcal{E}V : C &\rightarrow \text{Local} \rightarrow \text{Model} \rightarrow \text{Boolean} \\
 \mathcal{E} : E &\rightarrow \text{Local} \rightarrow \text{Model} \rightarrow \text{Value} \\
 C : B &\rightarrow \text{Local} \rightarrow \text{Model} \rightarrow \text{Boolean} \\
 V : VE &\rightarrow \text{Local} \rightarrow \text{Model} \rightarrow \text{Value} \\
 SE : SE &\rightarrow \text{Local} \rightarrow \text{Model} \rightarrow \mathcal{P}(\text{Value}) \\
 \mathcal{E}V[\text{for } V \text{ in } S, C] \text{ } t \text{ } m &= \\
 \bigwedge_{v \in m(S)} \mathcal{E}V[C] \{V \mapsto v\} \text{ } m &= \\
 \mathcal{E}V[\text{for } V = E_1 \dots E_2, C] \text{ } t \text{ } m &= \\
 \bigwedge_{v \in \mathcal{E}[E_1] \text{ } t \text{ } m} \mathcal{E}V[C] \{V \mapsto v\} \text{ } m &= \\
 \mathcal{E}V[B] \text{ } t \text{ } m = C[B] \text{ } t \text{ } m &= \\
 C[B] \text{ } t \text{ } m = \neg C[B] \text{ } t \text{ } m &= \\
 C[B_1 \text{ and } B_2] \text{ } t \text{ } m = C[B_1] \text{ } t \text{ } m \wedge C[B_2] \text{ } t \text{ } m &= \\
 C[B_1 \text{ or } B_2] \text{ } t \text{ } m = C[B_1] \text{ } t \text{ } m \vee C[B_2] \text{ } t \text{ } m &= \\
 C[V \text{ in } SE] \text{ } t \text{ } m = \{V\} \in SE[SE] \text{ } t \text{ } m &= \\
 C[VE = E] \text{ } t \text{ } m = (V[V] \text{ } t \text{ } m = \mathcal{E}[E] \text{ } t \text{ } m) &= \\
 C[VE < E] \text{ } t \text{ } m = (V[V] \text{ } t \text{ } m < \mathcal{E}[E] \text{ } t \text{ } m) &= \\
 C[VE <= E] \text{ } t \text{ } m = (V[V] \text{ } t \text{ } m \leq \mathcal{E}[E] \text{ } t \text{ } m) &= \\
 C[VE > E] \text{ } t \text{ } m = (V[V] \text{ } t \text{ } m > \mathcal{E}[E] \text{ } t \text{ } m) &= \\
 C[VE >= E] \text{ } t \text{ } m = (V[V] \text{ } t \text{ } m \geq \mathcal{E}[E] \text{ } t \text{ } m) &= \\
 C[\text{size}(SE) = C] \text{ } t \text{ } m = \mathcal{E}[\text{size}(SE)] \text{ } t \text{ } m = C &= \\
 C[\text{size}(SE) > C] \text{ } t \text{ } m = \mathcal{E}[\text{size}(SE)] \text{ } t \text{ } m > C &= \\
 C[\text{size}(SE) < C] \text{ } t \text{ } m = \mathcal{E}[\text{size}(SE)] \text{ } t \text{ } m < C &= \\
 V[V, R] \text{ } t \text{ } m = y \text{ such that } \langle \langle V, y \rangle \in m(R) &= \\
 \mathcal{E}[\text{size}(SE)] \text{ } t \text{ } m = \mathcal{E}[SE] \text{ } t \text{ } m &= \\
 \mathcal{E}[V] \text{ } t \text{ } m = \{V\} &= \\
 \mathcal{E}[E, R] \text{ } t \text{ } m = y \text{ such that } \exists z, z \in \mathcal{E}[E] \text{ } t \text{ } m \wedge \langle z, y \rangle \in m(R) &= \\
 \mathcal{E}[E_1 \oplus E_2] \text{ } t \text{ } m = \text{primop}(\oplus, \mathcal{E}[E_1] \text{ } t \text{ } m, \mathcal{E}[E_2] \text{ } t \text{ } m) &= \\
 SE[S] \text{ } t \text{ } m = \{s \mid s \in m(S)\} &= \\
 SE[V, R] \text{ } t \text{ } m = \{y \mid \langle \langle V, y \rangle \in m(R) \} &= \\
 SE[R, V] \text{ } t \text{ } m = \{y \mid \langle y, \langle V \rangle \in m(R) \} &=
 \end{aligned}$$

Figure 14 Denotational Semantics for Internal Constraint Language

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$R := Q, R \mid G \Rightarrow C$
 $Q := \text{for } V \text{ in } S \mid \text{for } (V, V) \text{ in } R \mid \text{for } V = E \mid \dots E$
 $G := G \text{ and } G \mid G \text{ or } G \mid G \mid E = E \mid E < E \mid \text{true}$
 $C := HE.\text{field} = E \mid HE.\text{field}[E] = E \mid V = E$
 $HE := V \mid HE.\text{field} \mid HE.\text{field}[E]$
 $E := V \mid \text{number} \mid \text{string} \mid E.R \mid E - E \mid E + E \mid$
 $\quad E * E \mid E / E \mid \text{size}(SE) \mid \text{element } E \text{ of } SE$
 $SE := S \mid V.R \mid R.V$

External Constraint Language

1600015

1600015

$h_v \in \text{HeapValue} = \text{Bit} \cup \text{Byte} \cup \text{Short} \cup \text{Integer} \cup \text{Struct}$
 $h \in \text{Heap} = \mathcal{P}(\text{Object} \times \text{Field} \times \text{HeapValue} \cup \text{Object} \times \text{Field} \times \mathbb{N} \times \text{HeapValue})$
 $v \in \text{Value} = \mathbb{Z} \cup \text{Boolean} \cup \text{string} \cup \text{Struct}$
 $l \in \text{Local} = \text{Var} \rightarrow \text{Value}$
 $s \in \text{Store} = \text{Value} \times \text{Value} \cup \text{Value}$
 $m \in \text{Model} = (P)(\text{Var} \times \text{Store})$
 $\mathcal{R} : R \rightarrow \text{Heap} \rightarrow \text{Local} \rightarrow \text{Model} \rightarrow \text{Boolean}$
 $\mathcal{E} : E \rightarrow \text{Heap} \rightarrow \text{Local} \rightarrow \text{Model} \rightarrow \text{Value}$
 $\mathcal{HE} : HE \rightarrow \text{Heap} \rightarrow \text{Local} \rightarrow \text{Model} \rightarrow \text{Object}$
 $\mathcal{G} : G \rightarrow \text{Heap} \rightarrow \text{Local} \rightarrow \text{Model} \rightarrow \text{Boolean}$
 $\mathcal{C} : C \rightarrow \text{Heap} \rightarrow \text{Local} \rightarrow \text{Model} \rightarrow \text{Boolean}$
 $\mathcal{SE} : SE \rightarrow \text{Local} \rightarrow \text{Model} \rightarrow \text{Value}$

$\mathcal{R}[\text{for } V \text{ in } S, R] h l m = \bigwedge_{v \in m(S)} \mathcal{R}[R] h l [V \mapsto v] m$
 $\mathcal{R}[\text{for } (V_1, V_2) \text{ in } R, R] h l m = \bigwedge_{(v_1, v_2) \in m(R)} \mathcal{R}[R] h l [V_1 \mapsto v_1][V_2 \mapsto v_2] m$
 $\mathcal{R}[\text{for } V = E_1 \dots E_2, R] h l m = \bigwedge_{v_i \in \mathcal{E}[E_i]} h l m$
 $\mathcal{R}[G] h l [V \mapsto v] m$
 $\mathcal{R}[G \Rightarrow C] h l m = (\neg \mathcal{G}[G] h l m) \vee \mathcal{C}[C] h l m$
 $\mathcal{G}[G_1 \text{ and } G_2] h l m = (\mathcal{G}[G_1] h l m) \wedge (\mathcal{G}[G_2] h l m)$
 $\mathcal{G}[G_1 \text{ or } G_2] h l m = (\mathcal{G}[G_1] h l m) \vee (\mathcal{G}[G_2] h l m)$
 $\mathcal{G}[G_1] h l m = \neg(\mathcal{G}[G_1] h l m)$
 $\mathcal{G}[E_1 = E_2] h l m = (\mathcal{E}[E_1] h l m) = (\mathcal{E}[E_2] h l m)$
 $\mathcal{G}[E_1 < E_2] h l m = (\mathcal{E}[E_1] h l m) < (\mathcal{E}[E_2] h l m)$
 $\mathcal{G}[\text{true}] h l m = \text{true}$
 $\mathcal{C}[HE, \text{field} = E] h l m = (\mathcal{HE}[HE] h l m, \text{field}, \mathcal{E}[E] h l m) \in h$
 $\mathcal{C}[HE, \text{field}[E_1] = E_2] h l m =$
 $(\mathcal{HE}[HE] h l m, \text{field}, \mathcal{E}[E_1] h l m, \mathcal{E}[E_2] h l m) \in h$
 $\mathcal{C}[V = E] h l m = (l(V) == \mathcal{E}[E] h l m)$
 $\mathcal{HE}[V] h l m = l(V)$
 $\mathcal{HE}[HE, \text{field}] h l m = b$ such that $(\mathcal{HE}[HE] h l m, \text{field}, b) \in h$
 $\mathcal{HE}[HE, \text{field}[E]] h l m =$
 b such that $(\mathcal{HE}[HE] h l m, \text{field}, \mathcal{E}[E] h l m, b) \in h$
 $\mathcal{E}[V] h l m = l(V)$
 $\mathcal{E}[\text{number}] h l m = \text{number}$
 $\mathcal{E}[V, R] h l m = b$ such that $(V, b) \in m(R)$
 $\mathcal{E}[E_1 \oplus E_2] h l m = \text{primop}(\oplus, (\mathcal{E}[E_1] h l m), (\mathcal{E}[E_2] h l m))$
 $\mathcal{E}[\text{string}] h l m = \text{string}$
 $\mathcal{E}[\text{size}(SE)] h l m = |\mathcal{SE}[SE] l m|$
 $\mathcal{E}[\text{element } E \text{ of } SE] h l m =$ given some ordering of $\mathcal{SE}[SE] l m$,
 pick element number $\mathcal{E}[E] h l m$
 $\mathcal{SE}[S] l m = \{s \mid s \in m(S)\}$
 $\mathcal{SE}[V, R] l m = \{v \mid (l(V), v) \in R\}$
 $\mathcal{SE}[R, V] l m = \{v \mid (v, l(V)) \in R\}$

Figure 16

Denotational Semantics for External
Constraint Language

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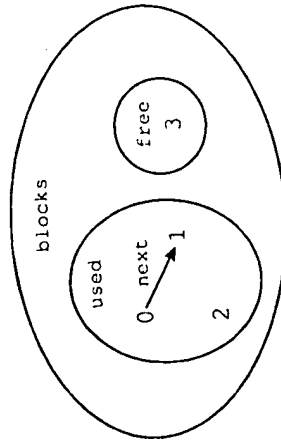


Figure 17 Repaired Model

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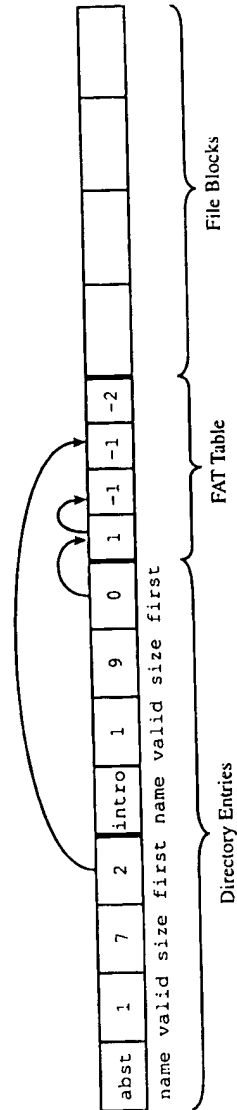


Figure 18 Repaired File System

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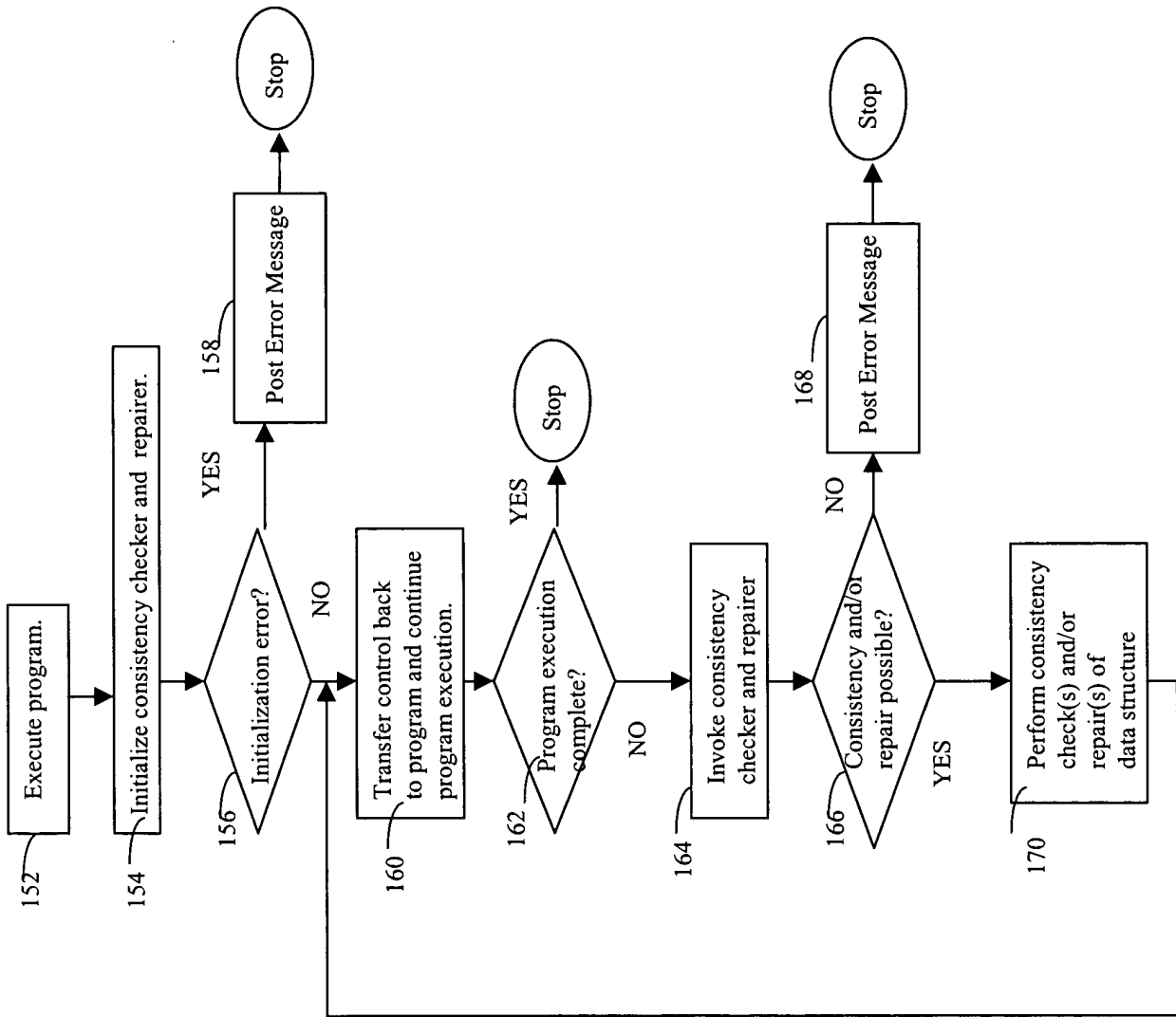


FIGURE 19

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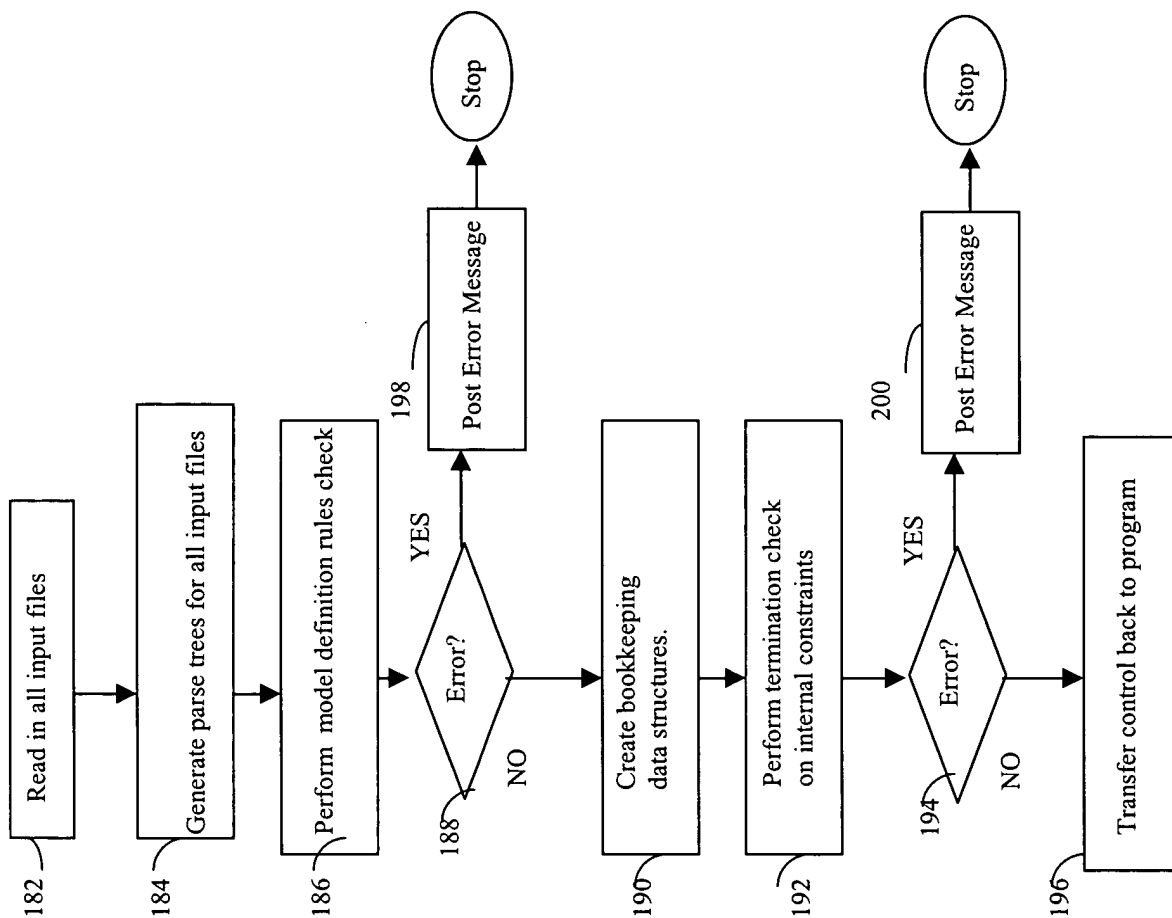


FIGURE 20

TITLE: SPECIFICATION BASED DETECTION AND REPAIR OF
ERRORS IN DATA STRUCTURES

Inventors: Brian C. Demsky, et al.

Filed: November 26, 2003

MIS-00401

Agent: Anne E. Saturnelli

Reg. No.: 41,290

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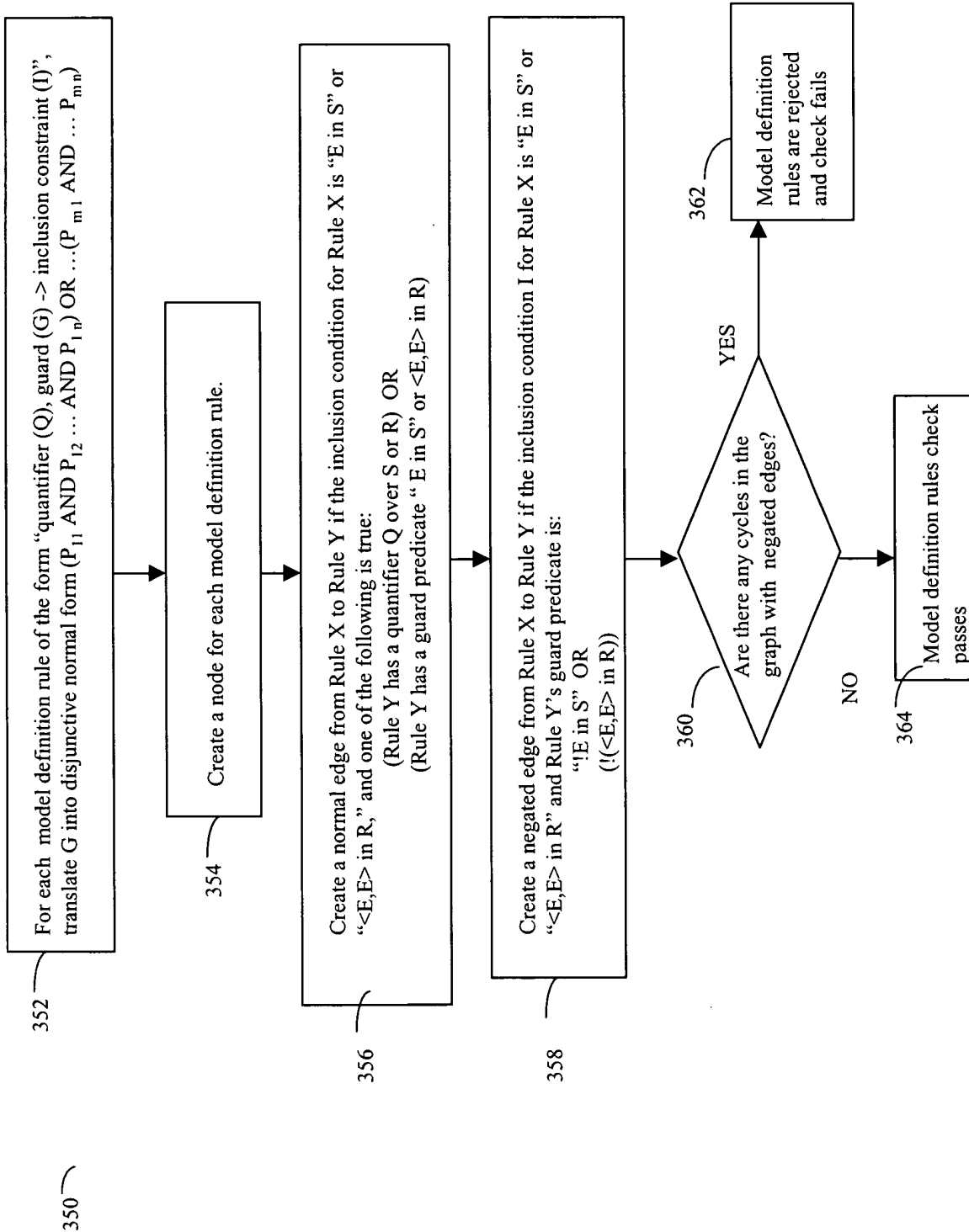


FIGURE 21

TITLE: SPECIFICATION BASED DETECTION AND REPAIR OF
ERRORS IN DATA STRUCTURES

Inventors: Brian C. Demsky, et al.

Filed: November 26, 2003

MIS-00401

Agent: Anne E. Saturnelli

Reg. No.: 41,290

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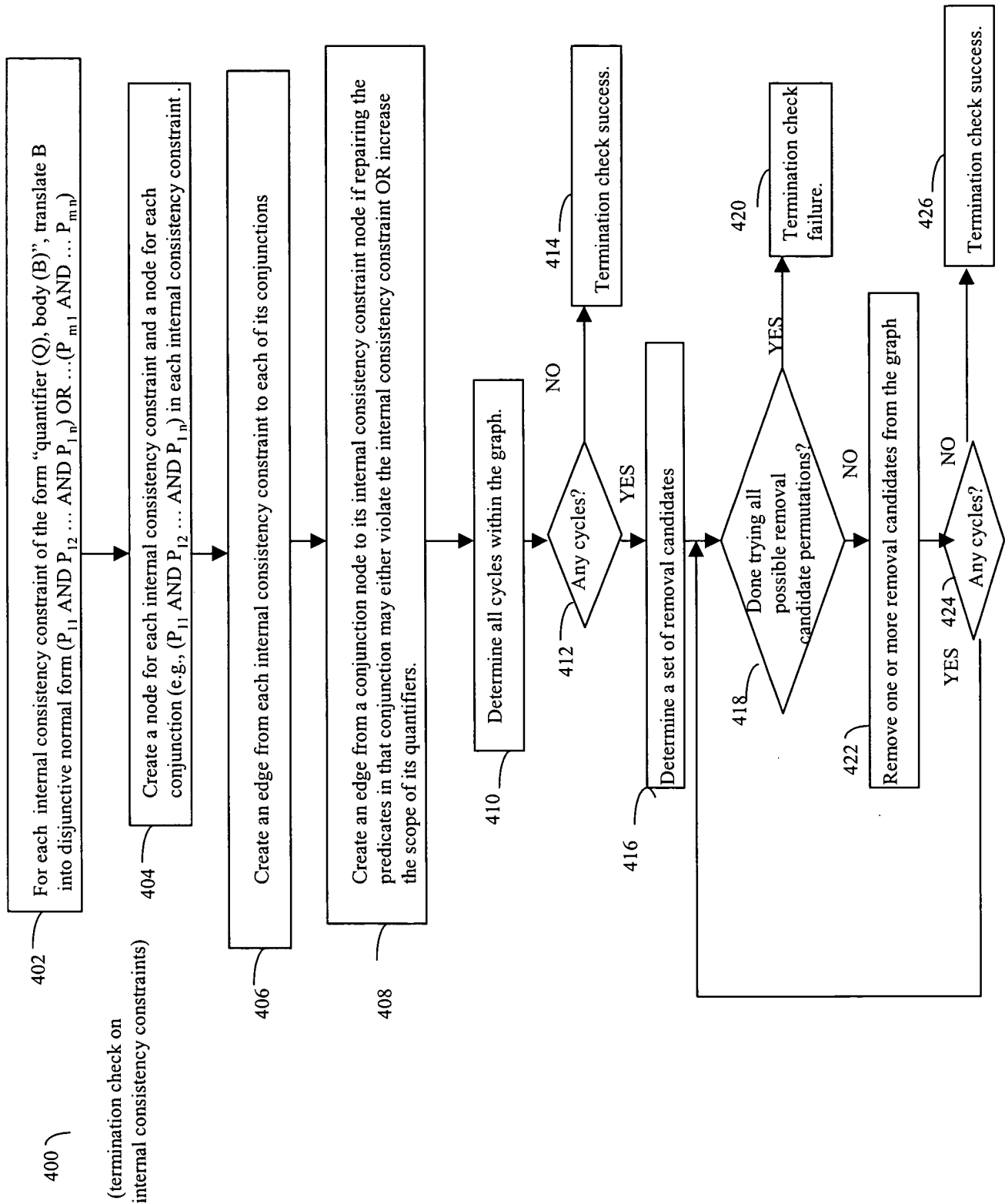


FIGURE 22

TITLE: SPECIFICATION BASED DETECTION AND REPAIR OF
ERRORS IN DATA STRUCTURES

Inventors: Brian C. Demsky, et al.

Filed: November 26, 2003 MIS-00401

Agent: Anne E. Saturnelli

Reg. No.: 41,290

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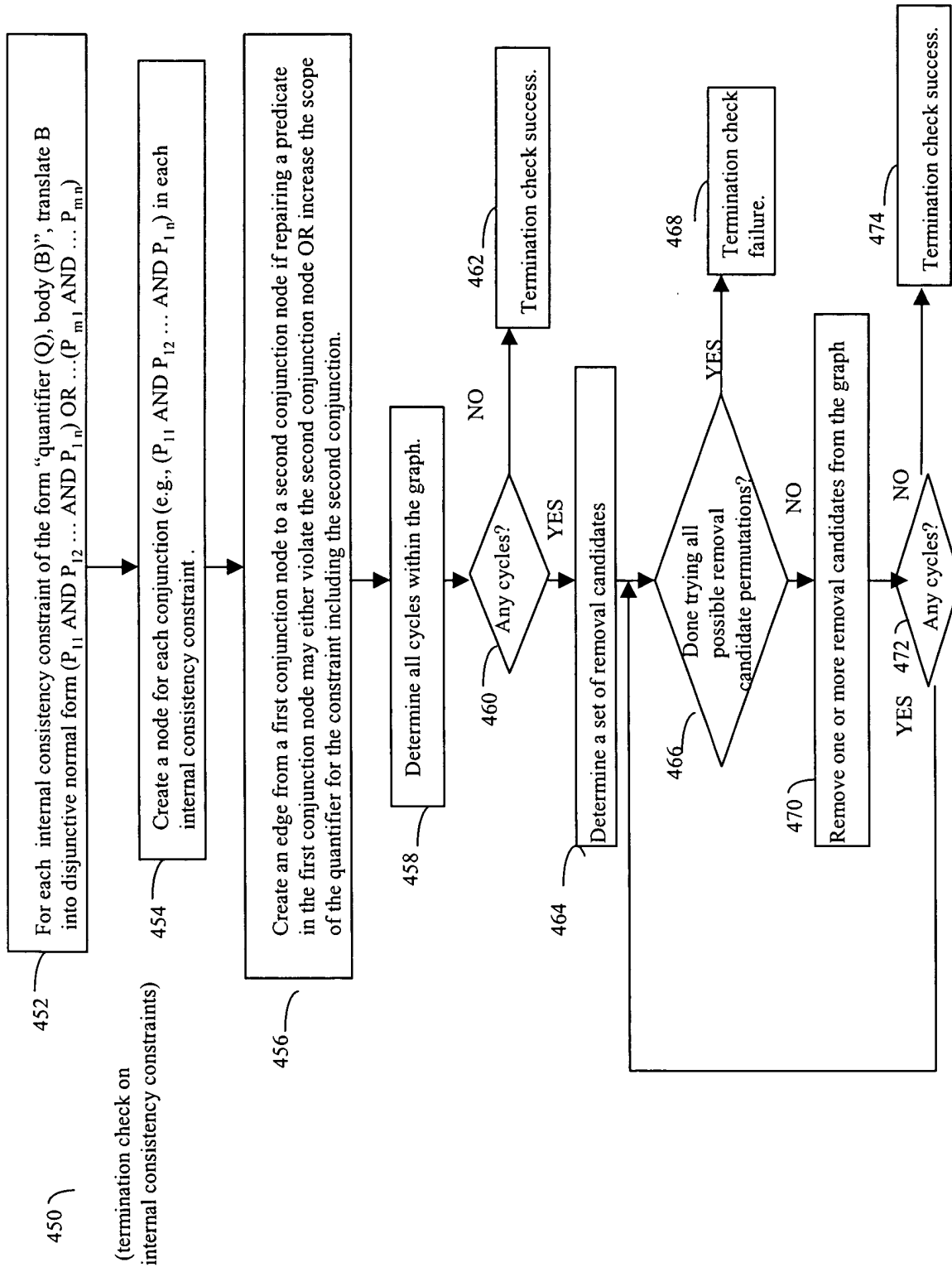


FIGURE 23

TITLE: SPECIFICATION BASED DETECTION AND REPAIR OF
ERRORS IN DATA STRUCTURES

Inventors: Brian C. Demsky, et al.

Filed: November 26, 2003

MIS-00401

Agent: Anne E. Saturnelli

Reg. No.: 41,290

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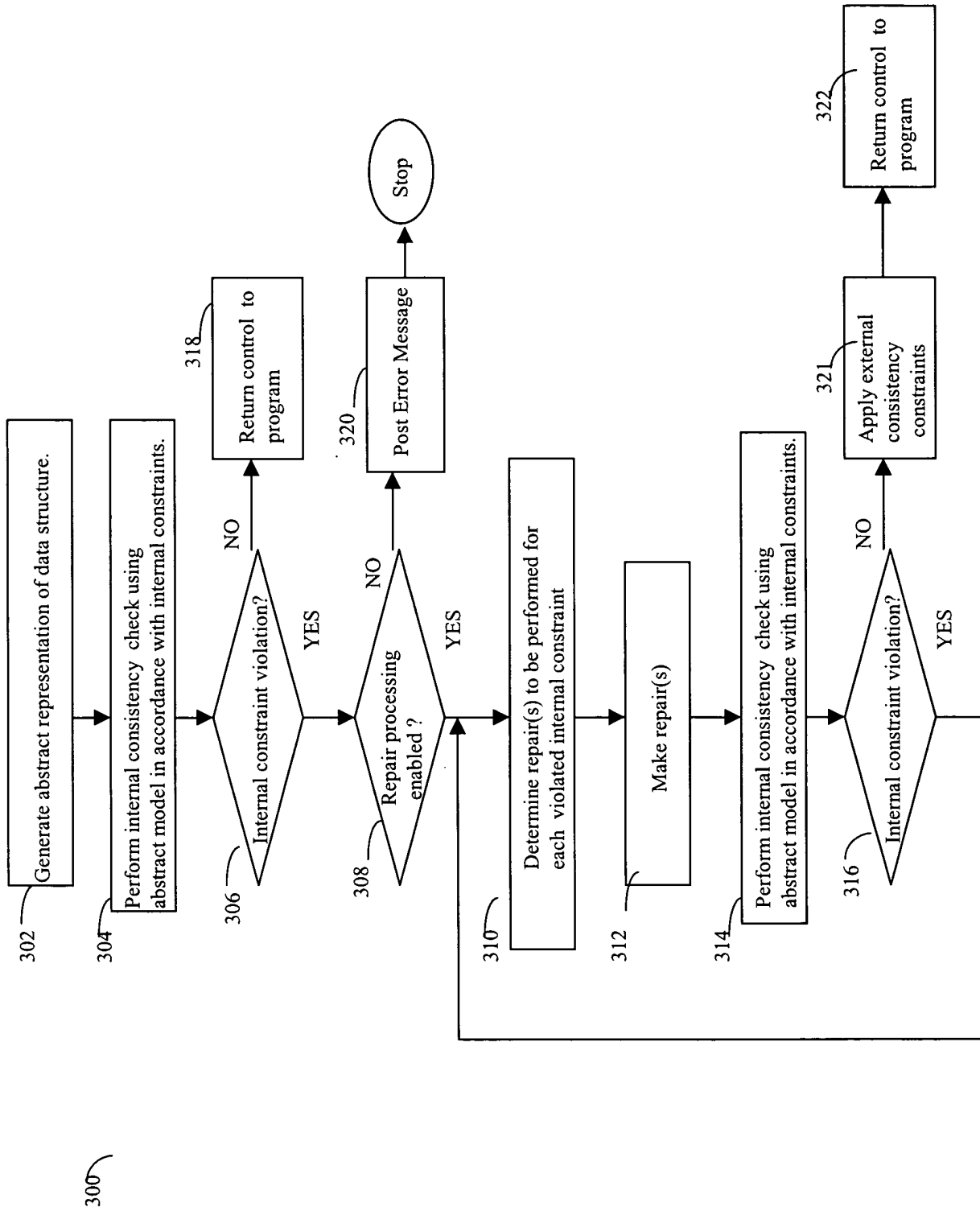


FIGURE 24

**TITLE: SPECIFICATION BASED DETECTION AND REPAIR OF
ERRORS IN DATA STRUCTURES**

Inventors: Brian C. Demsky, et al.

Filed: November 26, 2003

MIS-00401

Agent: Anne E. Saturnelli

Reg. No.: 41,290

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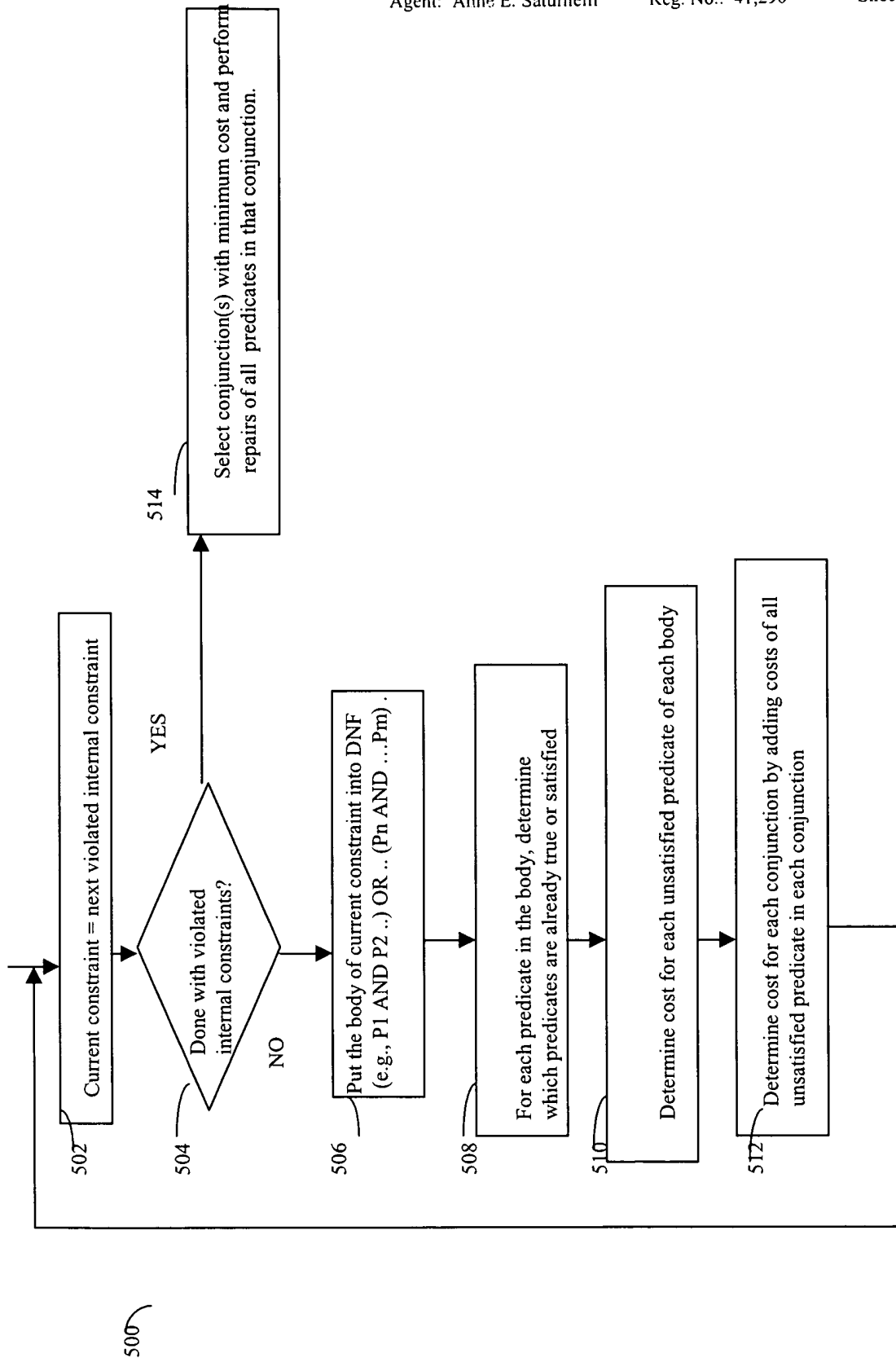


FIGURE 25

**TITLE: SPECIFICATION BASED DETECTION AND REPAIR OF
ERRORS IN DATA STRUCTURES**

Inventors: Brian C. Demsky, et al.

Filed: November 26, 2003

MIS-00401

Agent: Anne E. Satumelli

Reg. No.: 41,290

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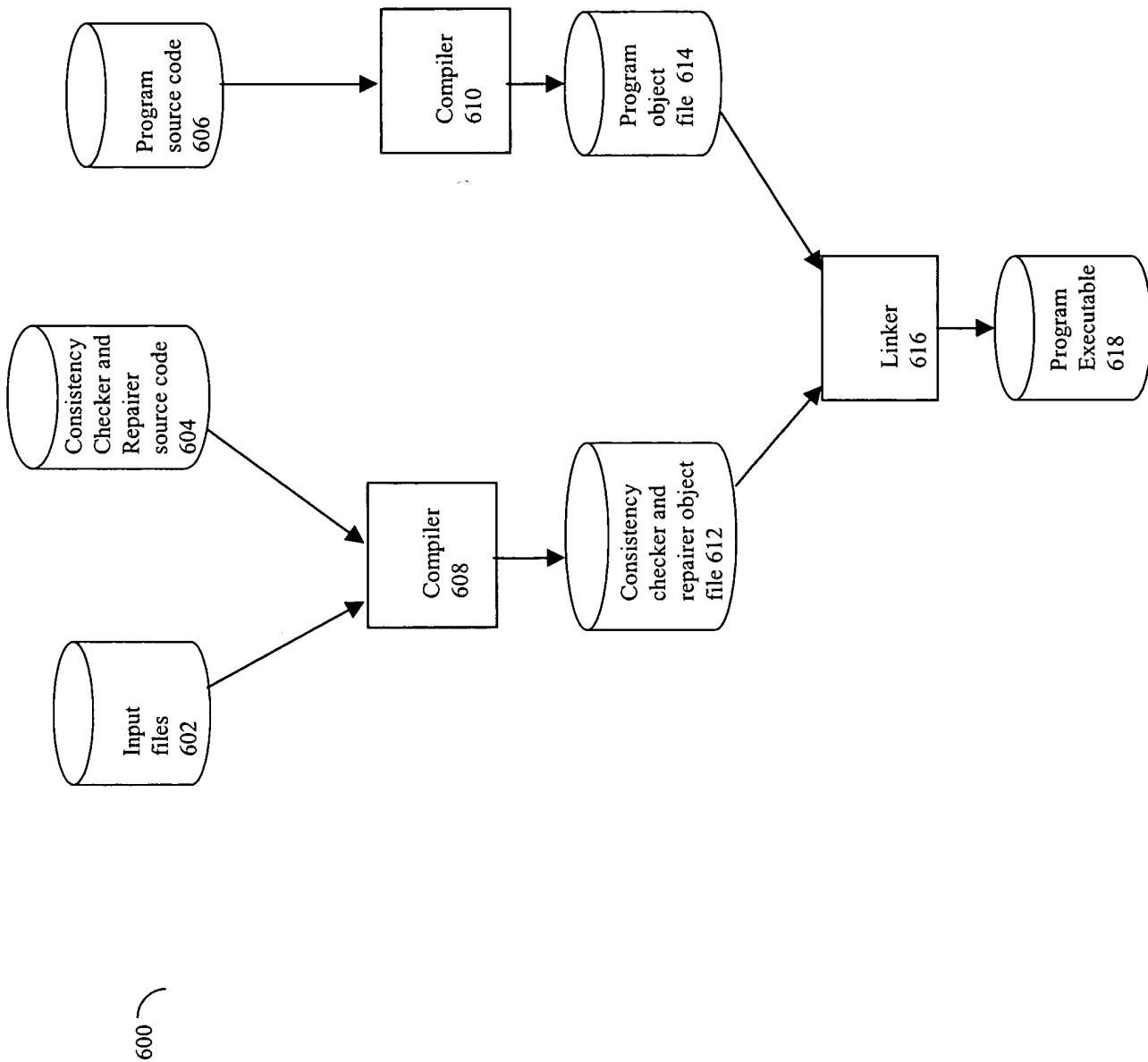


FIGURE 26

**TITLE: SPECIFICATION BASED DETECTION AND REPAIR OF
ERRORS IN DATA STRUCTURES**

Inventors: Brian C. Demsky, et al.

Filed: November 26, 2003

MIS-00401

Agent: Anne E. Saturnelli

Reg. No.: 41,290

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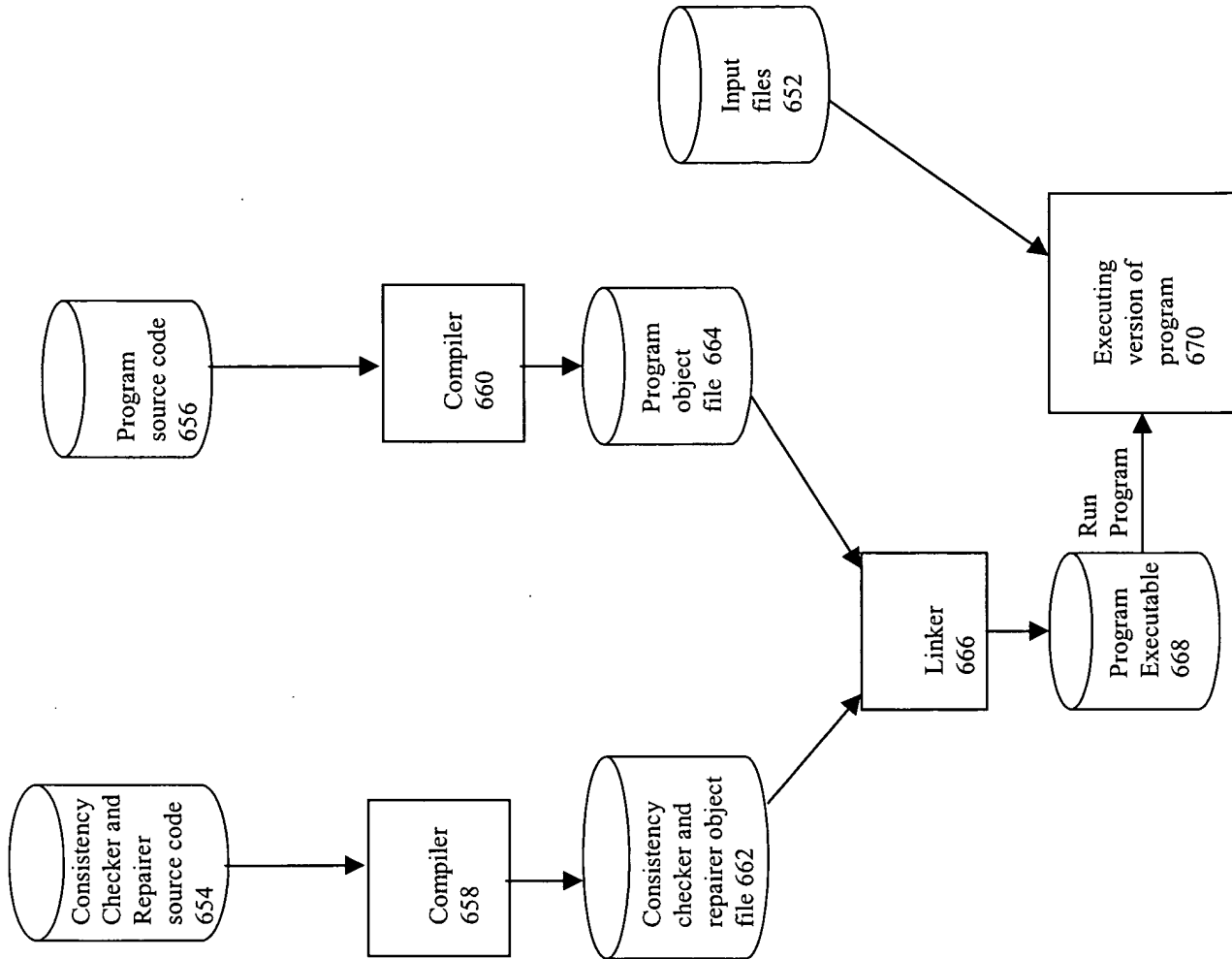


FIGURE 27